

White Paper

Report ID: 113074

Application Number: PF-50449-14

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Institution: Museum of History and Industry

Reporting Period: 10/1/2014-11/30/2016

Report Due: 2/28/2017

Date Submitted: 2/27/2017



WHITE PAPER

Grant number: PF-50449-14

“Analysis of Mechanical Systems and Building Envelope of MOHAI Resource Center”

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Historical Society of Seattle & King County dba Museum of History & Industry (MOHAI)

Date report is submitted: 2/28/2017

INTRODUCTION

The Museum of History and Industry (MOHAI) has become the preeminent institution in the Seattle region for engaging people in the exploration and understanding of the history, character, and development of the Puget Sound Community. The museum has achieved prominence in the Pacific Northwest through the strength of its collections and the excellent opportunities it has created for sharing them with the community. Spanning Seattle's history from 1851 to the present, the collections comprise roughly four million 2- and 3-dimensional objects.

MOHAI's 3-D artifact collections include more than 100,000 objects that represent Seattle history: maritime equipment, artifacts related to local businesses and industries, locally designed and invented products, vehicles, furniture, fine art, decorative arts, toys, and more. MOHAI's clothing and textile collections encompass roughly 9,000 clothing objects, and over 3,000 accessories. These collections are home to the first down jacket made by Eddie Bauer, early 20th century shoes from the first Nordstrom store, couture gowns purchased in Paris by wealthy local socialites, futuristic uniforms worn by workers at the 1962 World's Fair, homemade costumes worn by demonstrators at the 1999 WTO protests, and fashionable contemporary clothing designed and made in Seattle.

The Sophie Frye Bass Library houses the museum's 2-D archive and research collections, including over four million photographs, as well as films, posters, maps, books, papers and ephemera. Highlights of the collection include an estimated two million news photographs from Seattle's oldest newspaper, the Post-Intelligencer, spanning the 1910s through the print paper's demise in 2009. The library also houses archival collections from prominent businesses like the Bon Marché and Frederick and Nelson department stores, and the Puget Sound Bridge & Dredging Company as well as a growing collection of more than 600 oral histories. MOHAI's partner organizations, the Puget Sound Maritime Historical Society and the Black Heritage Society of Washington State also store their collections in the library.

PROJECT BACKGROUND

In 2012, the Museum of History & Industry (MOHAI) moved its artifact and library collections into the MOHAI Resource Center, a 53,800 square foot renovated warehouse. Since that time, the building has struggled to achieve a sustainable and appropriate preservation environment, in spite of the installation of a new HVAC system. Of greatest concern are the Library and the Textile Storage Room, because these areas house some of the museum's most vulnerable materials. Extreme fluctuations in relative humidity (RH) as high as 66% and as low as 23% present a threat to the condition of the collection. Consultations with our building contractors resulted in a variety of theories and solutions, with a cost range of \$3,000 to \$133,000 to implement their proposals. Because the source of the problem remained a mystery, we could not be sure that any of these solutions would correct the issue.

With support from the NEH, MOHAI worked with Jeremy Linden and Chris Cameron from the Image Permanence Institute (IPI) of Rochester, NY to develop a better understanding of our mechanical systems and the effects of our building envelope on our storage environment in the context of the Pacific Northwest marine environment. The grant funded a two year project from October 2014 through September 2016. The project team consisted of MOHAI staff members and a complementary group of external experts. In addition to IPI staff, we worked with conservator Dana Senge, as well as Rebecca

Welch and Darren Boyle of Affiliated Engineers, Inc. These consultants were chosen because of their content expertise regarding best practices in museum preservation and mechanical engineering.

METHODOLOGY

The work plan called for extensive data collection over the course of eight seasons through the placement of additional Preservation Environmental Monitors (PEMS) throughout the spaces and in the Rooftop HVAC Unit, designated as RTU 2, which serves the Library and the Textile Storage Room. Two team meetings were scheduled on either side of the data gathering period, one in November 2014 and the second in December 2015. During the interim, we collected data and implemented supplemental actions suggested by the team.

Ultimately, by more closely analyzing the factors which influence the storage environment, we sought to be able to determine a sustainable strategy for the collections as well as the institution. We anticipate using the knowledge gained from this project as a starting point for making adjustments to the rest of the collection.

PROJECT ACTIVITIES

Thermal imaging to identify any abnormalities in the building envelope.

- **Key Learning:** While there is noticeable air intrusion and heightened pest activity within the building, there are no significant breaches in the building envelope. Air intrusion is not abnormal.
- **Action Taken:** MOHAI began caulking and sealing gaps in the building envelope to reduce pests. This work will continue but no significant investment of resources is required.

Placement and analysis of PEMS throughout the building to monitor temperature and RH fluctuations.

The two areas MOHAI identified environmental challenges, the Library and the Textile Storage Room, are both conditioned by RTU 2, a fifteen-ton standard DX rooftop unit. In addition to the PEMS placed throughout the building, three additional PEMS were placed inside RTU 2 to record outside air entering the unit, cooled air supplied to the building, and return air coming back from the building.

- **Key Learning 1: RTU 2 is short-cycling and conditioning inefficiently.** PEMS show that RTU 2 is locked in an inefficient cycle of alternating heating and cooling with the unit switching from sub-cool reheat to sub-cool heat mode, creating a conditioning band of 64-75°F. This cycle occurs at least five times a day (Figure 1).
- **Key Learning 2: Energy consumption is elevated.** A HOBO data logger installed on RTU 2 to determine

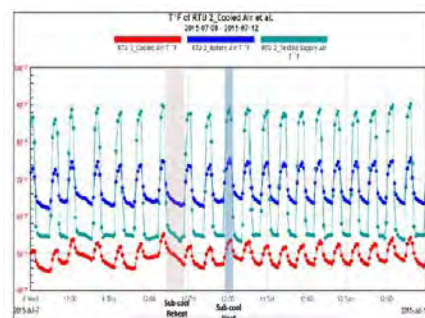


Figure 1: RTU 2 PEM Temperature chart demonstrates short-cycling July 7-12, 2015.

energy consumption showed a constant draw of 2.5 amps, indicating that even when the compressors and the condenser fans are not running, the supply fan still draws power. With short cycling, compressors run for 18 hours per day, drawing almost twice the energy when running two compressors. This shift from one to two compressors and back happens multiple times each day.

- Action Taken:** Using the PEM data, IPI recommended new settings for RTU 2 which were put into effect on March 11, 2016. Staff then tested system shut-downs. Daytime shutdowns of six to eight hours were tested for one week. The test proved successful, halting the equipment short cycling. During the shutdown period with no active mechanical system in operation, RH conditions for the library and textile room gently drifted lower but stayed within target range. This test provided valuable information regarding the ability of storage spaces to sustain a stable RH during previously volatile shoulder seasons and points to RTU 2 as the obstacle to stabilizing RH for these spaces. System shutdowns are not a viable long-term solution as a certain amount of ventilation air must be provided at all time per Seattle Department of Construction & Inspections Mechanical Code Chapter 4.
- Key Learning 3: RTU 2 is unable to maintain relative humidity as desired.** PEMs placed in RTU 2 demonstrated that interior relative humidity follows the fluctuations of the external environment, despite unit settings to intake as little outside air as possible. According to University Mechanical Contractors, Inc. who installed RTU 2, the unit is designed to maintain 40-50% RH assuming regular weather patterns. Overall, our region did not experience any abnormally severe weather patterns during the recorded time. However, Figure 2 demonstrates that during the two year grant period, the library and textile storage experienced numerous fluctuations in RH as well as sustained periods of high humidity and extremely low humidity.

PEMs indicate that the collections are most at risk for extreme fluctuations during shoulder seasons due to the unit's inefficiency. For example, in spring 2015, outside conditions at near-by Sea-Tac airport ranged from 28% to 90% RH, and in fall 2015, from 31% - 93% RH as recorded by the National Oceanic and Atmospheric Administration (NOAA). RTU 2 is unable to hold desired internal dew point due to the short cycling in the sub-cool reheat and sub-cool heating operation. As a result, library and textile areas experienced RH fluctuations between 28%-60% in spring (Figure 3) and 43%-67% in fall.

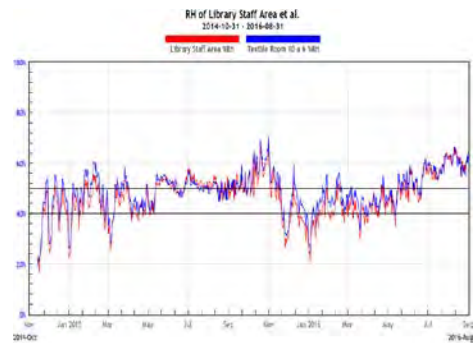


Figure 2: RH graph of library (red) and textile storage (blue) Oct 2014- Aug 2016.

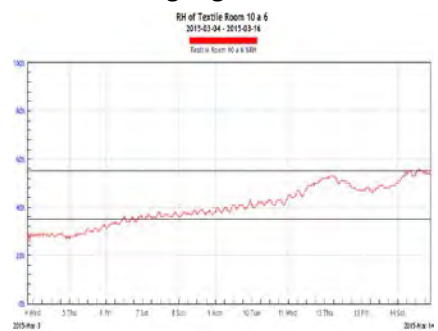


Figure 3: RH graph of textile storage March 4-16, 2015 indicates 29% fluctuation across 11 days.

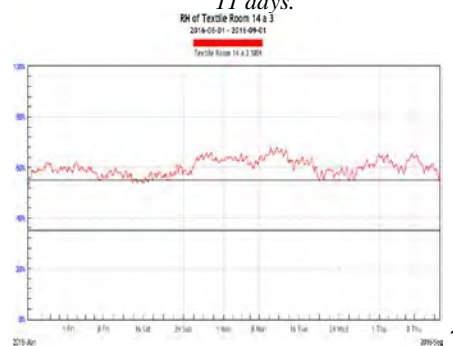


Figure 4: PEM RH graph of textile storage June-Sept 2016. Min RH 45%; Max RH 68%. Changes were not gradual enough to be considered seasonal drift.

Periods of sustained high humidity, as seen at right from June-Sep. 2016 also endanger the collections (Figure 4). RH higher than 55% creates a corrosion risk for metals and metal elements, and over 60% creates the potential for mechanical damage in vulnerable materials as well as risk for mold growth. After replacing a cooling coil in RTU 2 in Aug. 2015, and adjusting unit controls, Preservation Environment Evaluation metrics did improve overall. Yet, even with these changes, the supply air is not sub-cooled enough to remove enough moisture from the mixed air (recirculated air with a low percentage of incoming outside air). Consultants believe this is a mechanical limitation of RTU 2.

- **Action Taken:** Until a permanent solution is in place, staff have adjusted work schedules to refrain from working with affected collections during periods of dangerously low humidity.
- **Key Learning 4: The current library floor plan is not optimal.** Currently, with the exception of cold storage, the library is one open room that includes both storage and work spaces and is not completely buffered from the rest of the facility. The size of the room and the arrangement of the ductwork make it impossible to maintain both suitable storage and comfortable working conditions.

Due to its location on the rooftop and the layout of RTU 2 ductwork, the Library staff area is the first location served by the air supply. The main duct line then splits in two, sending a majority of the air into the textile area and the remainder to the library shelving area. With no reheats or humidification downstream, all zones receive the same conditioned air. A 10°F delta is seen from the supply to the return air condition. This means that RTU 2 must supply 57°F air to the space to create a 67°F space temperature in the shelving area. This slight warming of air as it moves through the ductwork causes additional, unnecessary energy consumption to maintain appropriate conditions at the duct terminus. It also causes the work area to experience a condition that is slightly cooler than the rest of the space. Separating the storage space from the space staff work with collections would lead to increased climate control and improved energy consumption.

CHALLENGES AND CHANGES DURING THE GRANT PERIOD

The primary challenge to this project was the fact that there is no Building Management System in place to easily change the settings on the RTUs. All programming must be done on the roof, at each device, manually using a hand held device. This complicated our efforts to test shutdowns, adjust settings, or respond quickly to changes in weather.

Additionally, personnel changes during the course of the project resulted in modifications to our original methodology. Martha Aldridge, Chief Relocation Officer for the museum, retired in December 2014. Dr. Aldridge was a strong advocate for the collections in addition to her role as administrative and fiscal manager for the renovation of the Resource Center. She was able to interpret and communicate the broader perspective of the administration throughout the renovation process. Her absence means that we have less ability to evaluate and present this case study in the greater context of a museum organization.

In contrast, we gained expertise with the June 2015 hiring of Jason Young, MOHAI's Senior Manager of Facilities and Security. His knowledge of HVAC systems has added a greater level of capability to our staff than when we began the project. However, his responsibilities for the management of two buildings impacted his availability and the access to the roof top units.

Ongoing mechanical issues with RTU 2 also disrupted our plans to test overnight set-backs and weekend shutdowns. In May 2015, RTU 2 developed a refrigerant leak in the cooling coils. Due to the inaccessibility of the leak, the entire coil section of the unit was replaced in August 2015. Interestingly, when analyzing the data from this time period, IPI staff noted that the interior conditions were actually more stable when the unit was operating on just one coil, instead of two. However, during the repair we also discovered that the PEM recording conditions of the cooled air inside RTU 2 had malfunctioned. The PEM was shipped back to IPI and a spare was put in its place, but we have no data from 8/4/15 to 8/15/15.

ACCOMPLISHMENTS

Ultimately, we determined that the fluctuations in RH were the result of the mechanical limitations of RTU 2. Attention to seasonal changes revealed which factors had the greatest influence at any particular time, eliminated previous hypotheses as well as helped identify and resolve key issues with the HVAC unit settings. This knowledge evolved and developed with the input of the team members. The MOHAI staff no longer felt they were operating in a crisis mode.

One key to understanding the behavior of RTU 2 was grasping the relationship between the mechanical equipment and the Pacific Maritime weather.

The Pacific Northwest climate is considered to be similar to that of the Mediterranean: mild year-round temperatures, abundant winter rains, and dry summers. These conditions are due to the influence of the Pacific Ocean and the jet stream as it approaches the West Coast. In the summer, the jet stream is weaker and shifts to the north bringing drier conditions from the landmass to Seattle. In the winter it is much stronger and typically picks up moisture from the Gulf of Alaska or lower areas of the Pacific Ocean before meeting the coast. The seasonal transition periods occur in March through May, and in late September and October. One reason the mechanical system is struggling with moisture control in the fall and spring is because the dew point is already high during these cool and rainy seasons. The current HVAC system can only dehumidify by cooling the air, in turn causing condensation which can then be removed. However, if the air is already cool, the mechanical system can't effect any change to the moisture content, and it continues to send humid air into the room. These mechanical limitations are impeding our ability to create optimal storage conditions for our collection. If we are able to add a component to dehumidify the space, there is significant potential for improvement.

Conversely we determined that it was not worth the cost and effort to add humidification, because the data demonstrates that low RH readings occur for only short periods of time in the winter. If we change our work processes to avoid handling objects on those days of extremely low RH, we can mitigate potential risk to the collection during these periods. We also determined that if we are able to reduce

the amount of time that RTU 2 is operating, we can maintain a stable environment and save money on energy costs.

Each consultant produced a final report (Appendix A - C). The project met its goal by quantifying the periods when the collections are at peak preservation risk, by identifying reasons for these interior climate variances, and by developing a plan for implementation.

AUDIENCE

The audience for this project was primarily internal. The Collections and Library Departments requested the funding in order to solve the problem of inappropriate conditions for the collections in storage. We also needed the expertise of outside consultants to expand our knowledge of the situation and demonstrate to our administration that a problem exists and a more sustainable solution could benefit the museum in the long run.

However, we felt the project may also be of interest to other museums. While there are increasingly greater examples of sustainability projects from museums on the East Coast, it was difficult to find examples that addressed the Pacific Maritime environment of Seattle. Many museum and library collections are maintained with less-than-ideal HVAC systems, and collections staff often don't have the expertise to determine the best solutions. While this project addressed specific questions about our building envelope and the Pacific Maritime climate, it also brought up broader questions about environmental conditions and sustainability. To that end, we will be presenting a session at the 2017 AAM Conference to share our experience (Appendix D).

CONTINUATION OF THE PROJECT

The information gained from IPI at the first grant meeting helped develop staff understanding of storage conditions. One of the general key learnings from the IPI consultants was that flat line conditions (temp and RH which remain constant throughout the year) are no longer viewed as the only acceptable climate conditions for collections. New data shows that limited fluctuations may have little or no negative impact on collection items, but may be substantially more energy efficient to maintain.

This helped inform changes that went beyond the library and textile spaces in the storage facility. At the main museum, each artifact case that holds a large textile is connected to an individual unit that controls humidity. These units have a reserve of water that either empties as humidification is needed or fills as humidity is removed. The units were first installed in the winter, and the staff quickly discovered that a large amount of monitoring and upkeep was needed as the bottles were constantly in need of being refilled. At the time the humidity was set to be 50% year-round. If a bottle wasn't refilled quickly enough it would empty and the humidity would drop as low as 30%. But after the first grant meeting and the new information from IPI about acceptable fluctuations and seasonal drift, staff was able to re-think this system. We learned that 50% is on the high end for safe humidity for textiles. Slightly drier (40-45%) may be better, but if one is creating a year-round setting, that can be difficult to achieve in the summer. With this in mind, Collections Specialist Clara Berg now allows the humidifiers to

go down as low as 40% RH in the winter, and up to 50% in the summer. These settings are much easier for the units to achieve and it is now rare that we find the reserves empty and the humidity levels too low. Staff time spent checking and maintaining these units has been dramatically reduced.

Monitoring continues with a reduced number of PEMS and we have solidified our strategy for improving the collections preservation environment as well as the sustainability of the organization. We have applied for an NEH Implementation Grant to assist us in construction funding.

MOHAI proposes the following methods to implement an HVAC system capable of sustainably achieving target preservation conditions of 65°F \pm 3-5° and 40% RH \pm 3-5%, based on the outcomes of the NEH Planning Grant. MOHAI hired McKinstry, a Seattle-based full-service design, build, operate, and maintenance firm to review recommendations and to develop an implementation plan that combines both mechanical and non-mechanical improvements. These recommendations must be enacted collectively to correct MOHAI's fluctuating relative humidity and increased energy consumption.

Non-Mechanical Improvements

- **Build a wall in the library.** Building a wall to separate library storage from the space staff and researchers use to work with the collection provides greater climate control with improved energy consumption. Currently, RTU 2 works to but fails to condition the entire library to preservation-appropriate targets and is experiencing a 10°F delta from supply to return. Separating the spaces and providing each with a dedicated RTU will improve conditions and increase sustainability.

Mechanical Improvements

- **Replace existing RTU 2 with three new, properly sized packaged rooftop units with hot gas reheat dehumidification.** As stated above, RTU 2 conditions the library and textile storage—spaces that require the same preservation conditions. IPI believed that RTU settings could be modified for increased performance, and this is reflected in their report. However, mechanical engineers McKinstry evaluated MOHAI's roof top units and found that RTU 2 is oversized for the load it is conditioning and will not be able to perform as desired despite modified control settings, evident in the unit's inability to dehumidify and continuous short-cycling. While the conditions required by the textile and library storage spaces are the same, the effect of the materials on their environment, their exterior environment influencers (location of each space within the building), and the differences in their interior construction (drop ceiling in library and open air ceiling in textile storage) create distinct conditioning needs. Textiles hold the relative humidity to a greater extent than the library materials, due to a greater amount of exposed (hygroscopic) material as compared to library materials which are stored in cabinets and on compactor shelves. McKinstry has proposed removing RTU 2 and replacing it with three properly sized units, one for the textile storage, one for library storage, and one for the newly isolated library space, created by the addition of a wall outlined above, where staff, volunteers, and researchers will work with library collections. Each RTU will have the capacity to be programmed to meet the unique needs of each space.

- **Re-zone existing spaces within the building.** Each space will have individual controls to allow for unique adjustments and optimal unit performance and sustainability. Staff will test different set points within each space to optimize sustainability and preservation environment.
- **Installation of fans in textile storage.** This will combat stratification by more effectively moving the air and reducing stagnation. By creating more uniform conditions throughout textile storage, the fans will also reduce energy output of the new RTU conditioning the space.
- **The installation of a Building Management System to provide increased control over and monitoring of mechanical HVAC systems.** Currently, without a Building Management System, staff must work with a technician to access the roof and implement all programming manually at each unit, using a handheld device called the modular service tool. Under such circumstances, adjustments and changes to the system are difficult to test. A Building Management System would use BACnet compatible controllers to connect all of the rooftop air conditioning units, fans, room temperature sensors, relative humidity sensors (where applicable for library and textile spaces), equipment status monitors, and outdoor air conditions to an easily accessible location. Extensive performance data will alert staff when interior conditions do not meet requirements. Trending data on internal humidity levels will verify that the interior conditions are adjusting in a steady seasonal drift. Such alerts will allow Facilities Manager Jason Young to react efficiently to equipment mechanical errors and to adjust equipment set points to meet target conditions.
- **Positively pressurize storage spaces to minimize infiltration, lowering energy usage and allowing systems to more effectively manage humidity from the exterior.** With the current difficulties in adjusting HVAC settings, MOHAI has not been able to pressurize the building. Once the new systems are in place and connected via Building Management System, MOHAI will begin testing settings to achieve positive pressurization.

In their final report, IPI recommended MOHAI examine units RTU 6A and RTU 6B, which condition 3D artifact storage spaces, to determine if these units suffer from the same issues displayed by RTU 2. The NEH Planning grant did not include the extensive data collection and analysis on 3-D artifact storage that was conducted in the textile and library storage spaces. From MOHAI's monitoring, 3-D storage has not demonstrated the severity of RH fluctuation and extended period of elevated RH that the other two spaces are experiencing. MOHAI has prioritized actions to correct library and textile storage where preservation conditions pose a risk to the collections. Once all systems are all on a Building Management System, MOHAI will be better positioned to assess RTU 6A and RTU 6B performance.

GRANT PRODUCTS

Appendix A Report by IPI
Appendix B Report by AEI
Appendix C Report by Dana Senge
Appendix D AAM 2017 Annual Conference Session Proposal

Review and Analysis of Mechanical System Design and Operation

**Museum of History and Industry, Seattle, Washington
MOHAI Resource Center**

October 2014 – September 2016



Jeremy Linden, Senior Preservation Environment Specialist
Christopher Cameron, Sustainable Preservation Specialist
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PROJECT OVERVIEW

The Museum of History and Industry (MOHAI) contracted with the Image Permanence Institute (IPI) to conduct a review and analysis of the design and operation of the recently installed mechanical system at the MOHAI Resource Center as well as the building envelope. The goal was to determine the cause of environmental management concerns in the library and textile storage spaces, served by one of seven air handling units that serve the Center. The consultants were to provide recommendations for operation or system design changes to improve the preservation quality of storage environments and identify any available opportunities for energy savings. This project was funded by a National Endowment for the Humanities Sustaining Cultural Heritage Collections Planning grant, covering the period from October 2014 through March 2016. MOHAI asked for and received an extension of the grant period through November 2016.

IPI Senior Preservation Environment Specialist Jeremy Linden and Sustainable Preservation Specialist Christopher Cameron conducted this analysis over the period of one year including two three-day site visits. The MOHAI team involved with this project included Martha Aldridge, Betsy Bruemmer, Clara Berg, Donna DiFiore, Leonard Garfield, Jody Hendrickson, and Darby Riley. Primary activities included walkthroughs of both collections spaces, review of data gathered from MOHAI's preservation environment monitoring program, review of physical mechanical systems and the drawings and plans associated with them, and discussion of strategic goals and plans for preservation and collections management at MOHAI in the foreseeable future.

IPI deployed ten temporary loggers to collect data for the duration of the study and MOHAI purchased two years year of eClimateNotebook® on-line data management software at the Professional level as part of the project. The eClimateNotebook account was activated and set up prior to the visit and training was provided as part of the project.

This report represents the final deliverable from IPI to the Museum of History and Industry in fulfillment of the consulting agreement. Observations and recommendations on design, operation, and the achievement of preservation goals with the examined systems within the building follow.

Jeremy Linden
Chris Cameron
Image Permanence Institute
September 2016

MOHAI Textile Collection and Library Space—Executive Summary

The Museum of History and Industry includes two locations, the primary facility located on Terry Avenue and an auxiliary facility on Sixth Avenue South that is used as a Resource Center. The focus of this project was the Resource Center which was constructed in 1963 as a storage warehouse for marble countertops, and was remodeled in 2011-2012. The original site had no humidity control and very little heating or air conditioning. A complete upgrade of the mechanical system was needed before the museum could move in. The Resource Center currently houses a range of MOHAI collection types including textiles, photographs, firearms, silver, three-dimensional objects, maps, and library collections. The library and textile rooms served by air handling unit RTU 2 at the Resource Center were the primary focus of this investigation. The original target conditions that the collections staff were looking for in both the textile and library spaces was 65°F and 45% RH.

Mechanical System

When the Center was remodeled, several roof top units (RTUs) were added to the facility to handle multiple zones within the building. The sizes range from a small three-ton unit to two large twenty-ton rooftop units. These units are generally sold as package units (a standard model from the factory) with a few options. A seven-day programmable thermostat controls each unit. There is no building management system (BMS) in place to control or monitor the HVAC systems. All programming of the units must be done at each unit manually, using a handheld device called the modular service tool.

To program the units, a trained technician must service each unit individually. The technician needs to access the roof to open the side panel of the desired unit. While the side access panel is open, the technician then plugs the service tool in to make adjustments or to program the system. When the programming is complete the technician removes the device and takes it with him—MOHAI does not own a modular service tool. Therefore if any updates to the program are needed a service technician must be called in. Unfortunately without the tool and a trained individual immediately available, no adjustments or changes to the system can be made.

RTU 2

The unit that conditions the library and textile space is RTU 2, a fifteen-ton standard DX rooftop unit. In this system, the return air and supply air meet in a mixed air chamber, and the mixed air is first pulled across the filter medium and then across the cooling coil. Next, the air moves through the supply fan where it is pushed across the heating coil and then distributed to the collection spaces. (See Appendix A for a diagram of the system layout.) RTU 2 is located on the roof of the Center, directly above the library staff area. As air travels through the ductwork the first distribution point is the library staff area, which means that this space gets the primary push of air out of the unit. The main duct line then splits in two, sending a majority of the air into the textile area and the remainder to the library shelving area.

Zoning capability between the library staff, library storage, and textile storage areas does not seem to be available. Jason Young, Senior Manager, Facilities and Security, has stated that there were motorized ducts in the ductwork but apparently no ability to directly control

them. With no reheats or humidification downstream, all zones should receive the same conditioned air.

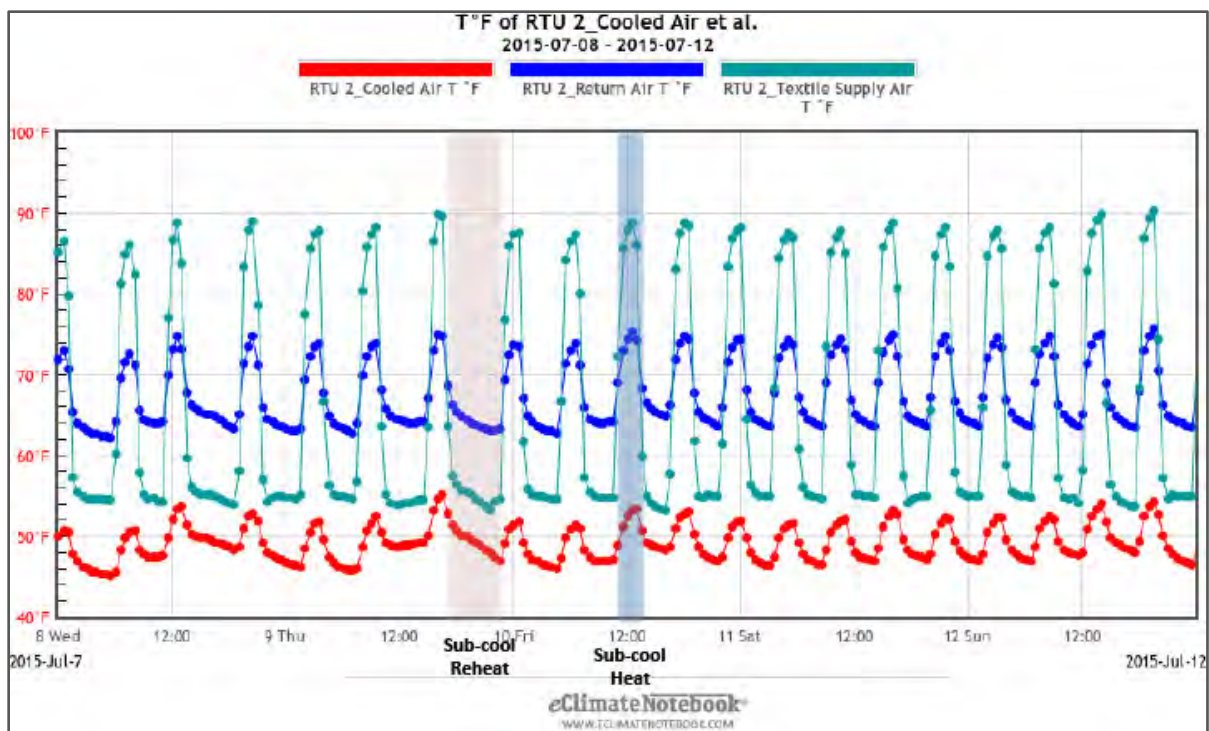
Air is returned to the unit from two return ducts located in the library staff area. There are no ducted returns directly from the library or the textile storage areas, and only a passive return in the textile space that is cut into the adjoining south wall of the library. The library collection space relies on air drawn up to the two return vents to return the air. Original prints for the facility show a third return was intended over the library collection area but was never installed.

A 10°F delta is seen from the supply to the return air condition. This means that the unit would need to supply 57°F air to the space to create a 67°F space temperature. Data shows that the return air temperatures in both the Textile and Library spaces are off a few degrees but track the same. Peak dehumidification for the system occurs during the shoulder seasons (spring and fall).

System Notes:

- Location: Resource Center Rooftop
- Layout: Standard rooftop unit design (The unit layout is shown in Appendix A)
- Type of Cooling: DX
 - The compressor/cooling coil on the unit is not equipped with a low ambient kit and is not designed to run if the outside temperature is under 35°F. This process is evident in the data in eClimateNotebook.
- Type of Heating: Indirect Gas Fired, 4 stages
- Filters:
 - MERV 8/30%
 - MERV 13/85%
- VFD: Yes. There is only a supply fan
 - The VFD reading for RTU2 at the time of the data pull was 43 HZ
 - This is compared to 37.5 HZ on RTU 6B and 38.01 HZ on RTU 6A
- Zone Served: The library and textile collection storage spaces
- Outside Air: Closed/minimal
 - Maximum outside air 400CFM
 - Outside air is controlled by enthalpy
- Economizer: Section and airside/disabled
 - Based on notes made available to the consultants the economizer for RTU 2 is dry bulb controlled.
 - The return air-dry bulb temperature must be 5°F below the outside air wet bulb temperature to enable the economizer.
- Humidification: None
- Design leaving dew point capability from the cooling coil: After the new coil was installed the unit appears to be able to produce a 40° dew point.
- Current Performance: There are a few issues with the unit. First, the unit is alternating between sub-cool heating and sub-cool reheat multiple times during the day. Second, the unit appears to switch into sensible cooling mode when it does not need to.

Based on available data, it is evident that the unit is almost always cooling to some degree. The unit appears to be fighting itself, creating a continuous loop by switching from sub-cooling reheat to sub-cooling with heating constantly. Using one loop as an example, it was noted that the unit operated in sub-cooling reheat mode until a temperature of 65°F was reached. At this point the unit switches into sub-cooling with heating mode for nearly two hours, warming the air until the space reaches 75°F. When the temperature reaches 75°F the unit switches from heating mode back into sub-cooling reheat mode. It is not clear whether it is the return air sensor or the room thermostat that controls the heating mode. This is causing an almost endless cycle of alternating heating and cooling with the unit switching from sub-cool reheat to sub-cool heat mode, creating a conditioned band of 64-74°F. This cycle occurs at least five times a day, and can be seen in both eClimateNotebook and power consumption graphs. The graph below illustrates this behavior over four days in July 2015.



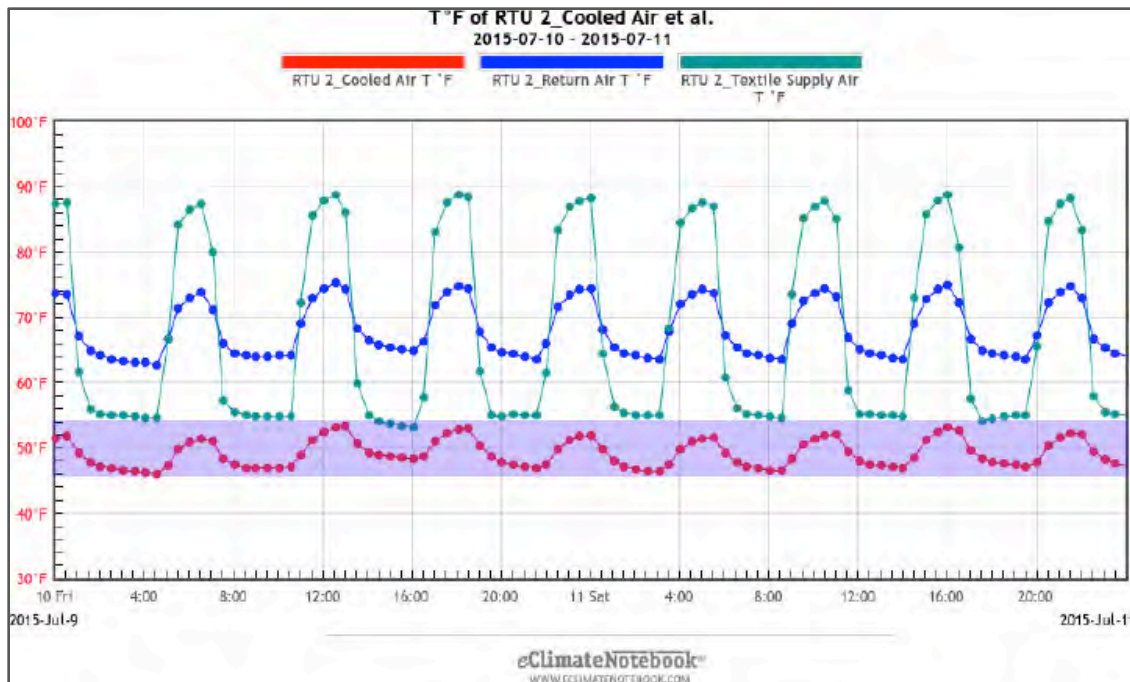
Sub-cool Reheat

When the unit is operating in sub-cool reheat mode, return air enters the unit at around 64-65°F. The cooling coil cools this air to around 48°F. Next the gas fired heater reheats the air to create a supply air condition around 55°F. The return air picks up 10 degrees of load in the space, causing the return air to be around 64-65° when it is brought back to the unit. The total amount of sensible energy used in this model is 23°F (16°F of cooling, 7°F of heating). Considering the desired temperature the museum is looking to achieve, this would be the preferred mode of operation.

Sub-cool Heat

In the sub-cool heat scenario, when sensor reaches 65°F the heating coil goes from reheat to heating mode. In reheat mode only one of the four stages of heating are used. When the

system turns into heating mode all four stages of heating are used. While in heating mode the cooling coil continues to run, however the temperature produced from the heating coil starts to overwhelm the air at the cooling coil. At its peak of operation the unit will keep trying to cool the incoming return air, however the cooling coil can no longer keep up with the return air temperature. Instead of the normal 48°F that the cooling coil produces, the temperature after the coil is around 52°F. The cooling coil has not changed operation and is producing a higher temperature. The heating coil then warms the incoming air to a condition of 88°F. This high supply air temperature causes the return air from the space to jump to around 74°. Including the work lost at the cooling coil there is a total of 62° of sensible energy used in this scenario (22°F of cooling, 36°F of heating, 4°F lost at the cooling coil). While operating in this mode the supply air condition can at times be warmer than the outside air. The following graph illustrates the effect of the heated air on the cooling coil, the fluctuations in return air and the textile space temperatures caused by the cycling over a two day period in July.



It is possible that the set points programmed into the unit are causing the units heating issue. The reset temperatures may be too close together and may be causing the heat to turn on more often than it is needed. Using the set points provided by Jason Young, the unit appears to call for heating at 65°F and cooling at 75°F. These numbers coincide with the data collected by the loggers. It has not been determined which sensor is governed by these set points.

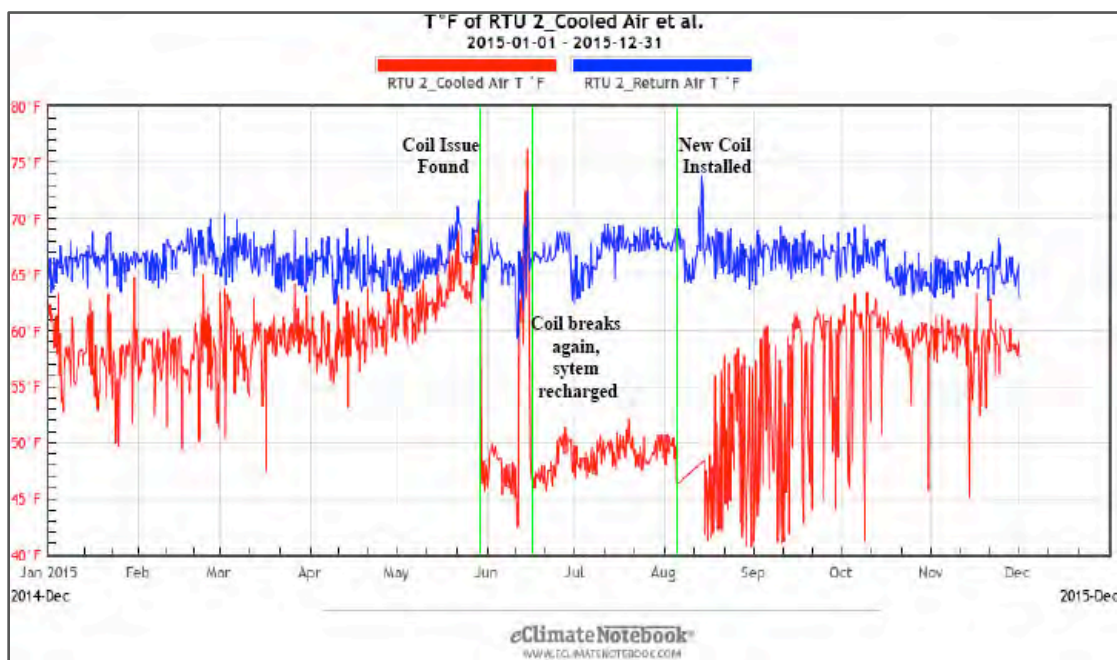
Some of the current set points programmed into by RTU 2 include:

- No cool Rst configuration: no Rst: 75.0 Then SAT: 50
- No cool Rst configuration: no Rst 72.0 Then Hi Rst: 50.0
- SA heating SETPOINT: 95.0 Hi Rst limit: 20
- No heat Rst configuration: no Rst: 68.0 Then SAT: 95.0

- No heat Rst configuration: no Rst: 65.0 Then Hi Rst: 120.0

Cooling Coil

An issue with the cooling coil was discovered on May 29, 2015 when it was discovered that the compressor was leaking. The leak was repaired and a recharge was given to the coil. On June 11 the condition of the unit had worsened. The unit was subsequently shut down and repaired again, including a recharge of the system. A replacement coil and compressor were installed on August 14. After it was recharged in May, the unit was producing a 47°F dew point (DP) which slowly leveled out to 48°-50°F after the second recharge in June. The new coil appears to be able to provide a better DP temperature at around 41°. The unit is unable to hold temperatures near that DP due to the back and forth in the sub-cool reheat and sub-cool heating operation. The graph below illustrates the temperature that is seen at different points during the issue with the cooling coil.

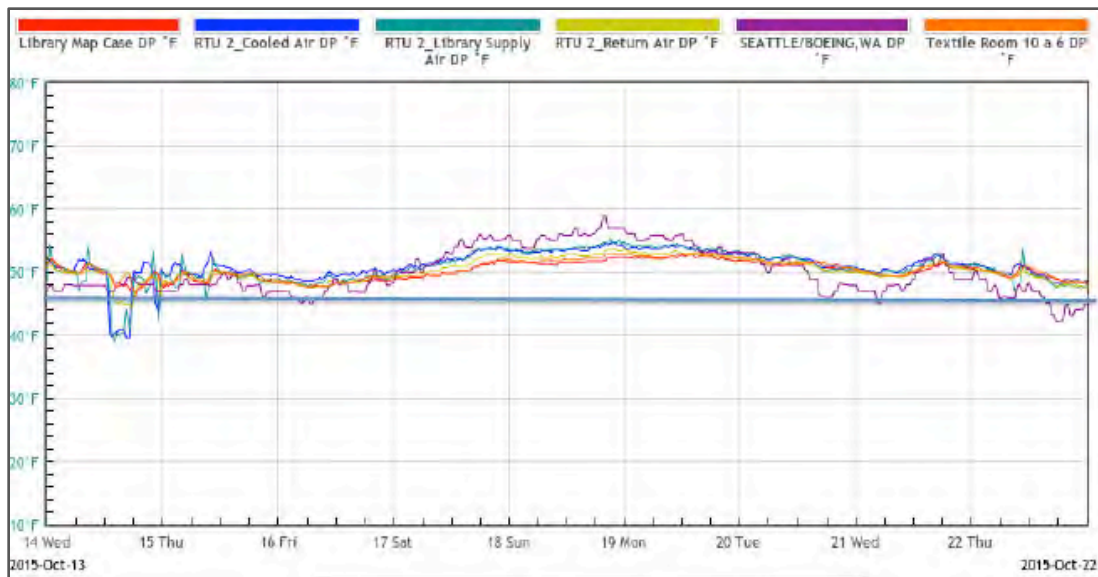


Sensible Cooling

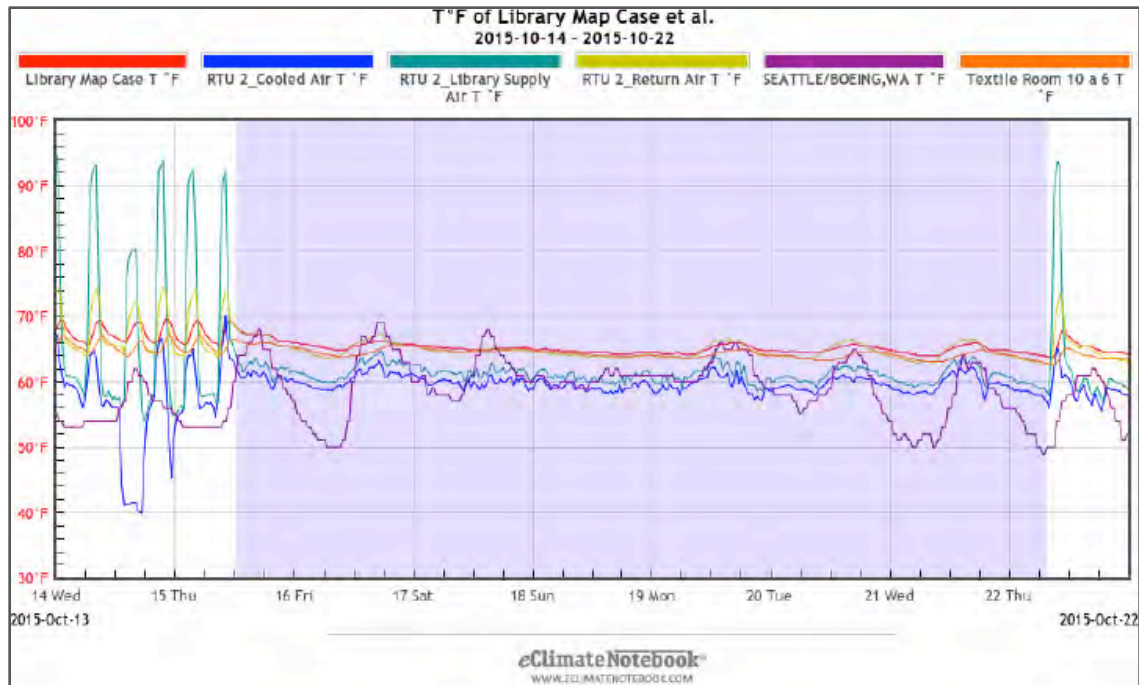
After the new coil was installed, the unit started to go through periods of sensible cooling instead of sub-cooling and reheating. On the morning of August 18, 2015 the return air temperature was around 65°F, the cooled air temperature was 57°F, and the outside air temperature was 62°F. While the use of outside air may have been a contributing factor, the economizer was disabled during this time. The data shows that the unit is operating in sensible cooling mode, meaning that the cooling coil is no longer working to remove moisture from the air, only to control the air temperature. At this time the reheat appears to provide only 2°F of heat to the supply air. Although it is not entirely clear what caused the switch into sensible cooling mode, it can be seen in both eClimateNotebook and on the power consumption graphs.

The system returns to steady sensible cooling mode around September 14, 2015. From October 16 to 21 there was an issue in the unit that caused the RH in the space to rise above

60%, a potentially dangerous situation for collections in these spaces. Based on available data, the system was in sensible heating mode at this time and was not dehumidifying at all. The supply air and cooled air dew points are higher than the dew point in the space. If the cooling coil was operating as needed, the space, cooling coil, and heating coil dew points would be 41-46°F, depending on the new coil's capabilities. The high dew points seen indicate that the cooling coil was not operating as it should. When the DP rises above 48°F, the new cooling coil should open fully and begin to bring the DP down. The switches are visible in eClimateNotebook and on the power consumption graphs as well. The graph below (for October 14 to 22) illustrates the dew point for multiple locations during the October incident.



During the same event, while the unit is in sensible cooling mode, the return air entering the unit is around 64-65°F. The air is then cooled to 59-60°F instead of the 41-46°F the unit is capable of. The supply air for the space is around 60-61°F. This information supports the conclusion that very little heating, if any, is added to the supply air. The average outside air temperature at this time was around 60°F and in some instances was higher than the space temperature. The graph below illustrates the temperatures at the time of the October incident.



In this sensible cooling scenario the outdoor temperatures may be stable enough to keep the interior temperature from dropping to a level that triggers the heating mode. One benefit from the sensible cooling incident may be that the facility has shown the ability to hold a temperature. If in the future MOHAI considers implementing a system shutdown, the data has shown that the system can hold its temperature enough to make the shutdowns successful.

It should be noted that the return air logger data from October 2014 to December 2015 is incorrect. The logger was placed in what was believed to be return air, however this was later found to be a passive return from the textile storage into the library. While this data was originally to be used as an example of the main return, it is instead an example of the return air exiting the textile room. The only returns directly to RTU 2 are in the front of the Library staff area. These returns are located directly over and to the north of the entry door.

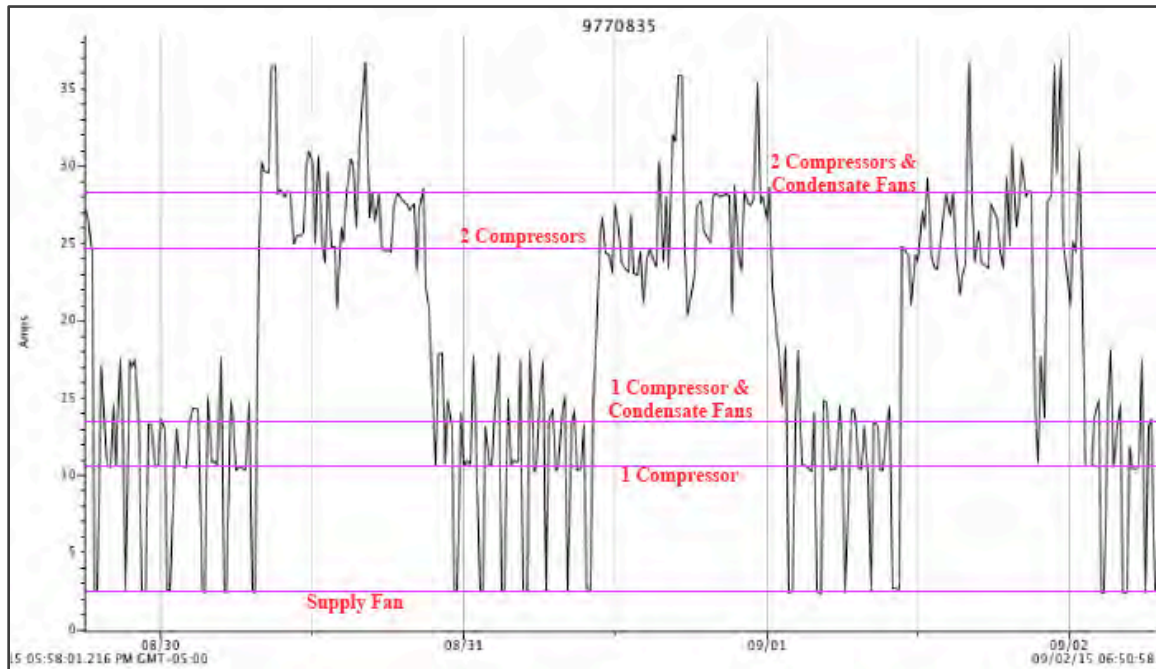
Power Consumption for RTU 2

A HOBO logger was placed in the unit's main power supply to determine power consumption by the unit. Data provided by this logger shows that the rooftop unit runs constantly, with no setbacks or downtime. A constant draw of 2.5A indicates that even when the compressors and the condensate fans are off the supply fan still draws power. The data also shows the great difference in power consumption when one compressor is running (in sub-cool reheat mode) and when two compressors are (sub-cool heat mode). The power draw for each component of RTU 2 is as follows:

- Combustion Motor 2.3 FLA
- Condenser Fan Motors 2.3 FLA /ea.
- Supply Air Motor 11A
- Compressor 1 12.6A

- Compressor 2 12.2A

The following graph shows the breakdown of RTU 2's power consumption. All events have been marked on the graph to provide insight into the power consumption and draw of the unit. As you would expect, the unit draws almost twice the energy when running two compressors as opposed to a single compressor. However, the switch from one compressor to two is not happening over months or days as part of a seasonal shift but rather multiple times a day as a side effect from the current system operation. It is also noted that the compressors on the unit run for a total of 18 hours a day.



Collection Spaces

The Resource Center as a whole has had pest issues. The staff has found multiple types of insects within the facility, including millipedes, springtails, tuxedo bugs, and moths in the collection spaces. Staff are currently caulking gaps that were noted around exterior doors and sealing doors to prevent more bugs from entering the facility. There was a recommendation to install screening materials on the vents between spaces to help prevent the transfer of insects between spaces, which was completed in the spring of 2016.

In 2015 MOHAI had an infrared (IR) study performed to find any major leaks or gaps in the facility's envelope, focused on the library and the textile storage areas. The IR study on the building interior did not find any major gaps or issues.

LIBRARY SPACE

The library is a 3,828 sq. ft. space near the center of the facility which houses library collections (books, documents, maps, posters, newspapers, CDs, DVDs, videotapes, lantern slides, etc.) and the library staff area. It was located in the center of the building so that the space would be buffered by the surrounding spaces. The original design for the space

included a dividing wall that separated collection and staff spaces, with separate mechanical units to condition each space. Unfortunately, the original design was altered and the final space is one large open room that uses a set of map cabinets and a door to separate the staff area from the collection space.

The staff area, which covers almost half of the library space, consists primarily of staff seating with desks, workstations and a conference table. The collection area consists of a row of flat files, a row of filing cabinets, and compact shelving. The compact shelving runs north to south. A section of metal shelving was added along the south wall in 2015.



The collection space is not completely buffered from the rest of the facility. The east wall and half of the north walls in the library are not full walls and terminate nearly a foot from the drop ceiling. The supply and return ducts from RTU 2 are located above the drop ceiling, which appears to use standard acoustic tiles. Air from the other connecting spaces treated by RTU 4 can mix in the open ceiling above the library and could potentially infiltrate the space. This air would be mixed with the space air and unfortunately, due to air return location, be pulled into RTU 2.

Due to the rooftop location and the layout of RTU 2, the staff area is the first location served—the first two diffusers from the unit are in this area. This causes the library to experience a condition that is slightly cooler than the rest of the space due to a slight warming of air as it moves through the duct work, making the air that exits the last diffuser in the textile or library collection area feel a degree or two warmer than the air in the staff area. Unfortunately, for the staff area there is little in the way to disrupt or disperse the air from the diffusers. In the collection area or textile room the shelving can act as a buffer and help to spread the air out and mix it before it reaches the floor. In the staff area there is nothing to stop the air from dropping straight down onto the staff, making ‘cold’ complaints common, especially when the unit is producing temperatures around 64°F.

There is a return from the textile storage space located along the south wall of the library collection area. This is a passive return only and any air that is drawn out of the textile room is dumped into the library collection area rather than ducted directly back to the unit. There is a noticeable difference in the air temperature coming from this return and the air in the rest of the space. The return air from the library collection area relies on the two-ducted returns in the front of the library staff area to draw air across the space.

A photograph collection is housed separately inside a walk-in cold storage unit connected to the library. The cold storage unit is located inside the storage space for three-dimensional objects and not inside the library walls, but is accessed through a door on the west wall of the library collection area. The environment of the cold room should have minimal impact on the library space.

The lighting for the space was designed to line up with the shelving in the collection area. The library space uses 31 four-bulb T8 fixtures for lighting. The lighting in the front staff area is spaced in standard office fashion with lights separated by ceiling tiles. The lights in the collection area are arranged in three rows of five, side by side, running east to west, with a few lights spaced out over the south aisle. Separate switches control the lights for the staff area and the collection area.

There are five data loggers in the library area to monitor different parts of the collection. One logger is inside the staff work area near the north wall, and the second is located directly over the entry door. This logger is recording the return air condition for RTU 2. A third logger located near the center of the library area, on top of the flat file storage, helps determine the mix of air that the room feels. The fourth logger is placed directly over the black file cabinets to monitor the supply air condition for the space. The fifth is located in the compact shelving to document the conditions experienced by the materials inside.

Temperatures across the space are similar throughout the year. The temperature for the map case is 65-67°F, 65-67°F in the staff area during the winter and 65-68°F in the summer, and 67-70° year round in the compact shelving. The reading inside the compact shelving may be warmer because the shelving is closed much of the time and the supply air is unable to reach all of the collections within. When the shelves are closed, the air will most likely exit the diffusers, strike the top of the compact shelving, and be pushed over the sides of the shelves rather than penetrate the solid walls to reach the collection inside.

Data from inside the compact shelving shows a DP temperature 1 to 2 degrees higher than the rest of the library spaces. The compact shelving does not feel the same unit cycling conditions as the other library and textile spaces. Keeping the storage unit closed to buffer this cycling may be beneficial to the collection stored on the shelves.

It was noted that during the morning tour of the facility the library staff area was 62°F. Walking through the facility just before lunch on the same day the logger was reading 64°F. Reviewing the data for that logger, 62° appears to be the low end or the start of the cycle, while 64° appears to be close to the high end of the cycle just before the unit reverts to the sub-cool reheat mode. Though the quick ups and downs of temperature may not have an immediate effect on the collection, the energy consumption to achieve them could be great.

The collections would benefit if the library staff area and the library collection space were separated from each other. This could be achieved by separating the two spaces into different RTU zones or even completely separate RTUs. It appears that the original intention of the building design was to completely separate these spaces. On an original set of prints, the library staff area was separated from the collections space and served by a different unit. In the final design the wall was not constructed and the only separation of the two spaces is a set of flat file cabinets. Both spaces are on RTU 2 and receive the same air.

If a wall was constructed there may be extra capacity on one of the other rooftop units to connect to the library staff area. A quick examination of the HVAC design prints compared to the units that are currently installed shows that there could be some capacity to add the library staff area to RTU 4. There is also the possibility of keeping the staff area on the same unit (RTU 2) but adding zoning capabilities to it. In this case the air could be separately

conditioned and delivered to each space. Without the need to treat the library collection the system could shut that zone down while still providing treated air for the staff area.

Despite the conditions in the library collection space, the data shows that the library staff area and the textile room conditions track each other. This may again be due to the same air being delivered to both spaces and the air's ability to directly reach the loggers and the collection, rather than the air being restricted from movement thorough the collection by the walls of the compact shelving.

TEXTILE STORAGE

The textile collections are stored in a 3,666 sq. ft. room located on the south side of the facility, adjacent to the library. This space contains a wide variety of collection materials including leather, paper, metal, glass, wood, ivory, celluloid, and rubber. The staff are very concerned that there are materials in this space that are more susceptible to dry conditions than to high moisture conditions. All collections are arranged on shelves, with few to no materials on the floor or in the work area. There are hanging textiles in the shelving area, grouped with other textiles, and these shelves are covered with muslin. Some items such as shoes are kept in the open while all other items are stored in boxes.



The envelope for the space is very basic. The walls are drywall with a base coat of white paint. The top half of the exterior walls are covered with an insulation barrier that is mounted directly to the block wall. The floor is unpainted or sealed concrete. The edges of the floor along the exterior wall had temperatures 20-25°F colder than the rest of the room. The floor temperature in this area should be inspected in the summer to watch for the possibility of condensation.

There is no drop ceiling in the space; the underside of the roof is visible from inside, nearly twenty feet from the ground. The textile room is equipped with 15 four-bulb T8 light fixtures, controlled by a main switch near the entry door. The space is equipped with emergency lighting designed to stay on at all times. The emergency lighting consists of two or three fixtures that are connected to other light fixtures. These fixtures do not generate an excessive amount of light or heat in the space.



All air that conditions this space is supplied by RTU 2. The 24-inch main supply duct enters the space through the north wall. This duct then splits into two 18-inch ducts with one half supplying air to the east half of the space and the other serving the west half of the space. The diffusers are located nearly eight feet over the shelving and distribute air into nearly every other row of shelving. There is no ducted return within the space. Air from the space is returned to the system through a passive vent on the north wall that connects to the library space. There are no other returns located within the space.

The textile space appears to experience a slightly muted version of what the library staff area feels. The winter conditions in the textile space are 62-66°F and 40-60% RH. The dew point during this period moves between 40-50°F with some downward spikes that span a few days. The summer conditions in the space are 63-68°F and 46-60% RH. The dew point in the summer is 46-50°F (averaging around 48°). Data indicates that the loggers in the east side of the space run slightly warmer than the logger in the west side during the summer. This may be due to slower movement of air from the east toward the return in the west.

The temperature of the supply air coming into the space is not enough to overcome the load inside the space. There is a 2-3° loss in temperature that is believed to be caused by the exterior wall. Though the wall is fully insulated it is believed that it may still play a factor in the space load. The library receives the same air and does not have the drop in temperature. The hard cycling that the system is experiencing can be seen not only on the supply temperature from this space but also on the return and in the data from the shelf loggers which shows 2-3° swings up and down. There is a concern that materials shelved on the top of the units could be exposed to very warm temperatures during the RTU 2 heating cycle. A logger in the textile room was moved to the top shelf to test the air for possible stratification or over heating issues.

The relative humidity in this space is also a concern to the staff. The data shows that throughout most of the winter the RH in the space is between 30-55%, well within a safe range for most materials. However, there are materials housed in the space that are more susceptible to dry conditions than to high moisture conditions. The MOHAI staff is concerned about the few days each year when RH levels drop below 25%, a condition that increases the risk of damage, especially when collections are being handled.

Though the data does show periods where the RH drops as low as 20%, the total number of days that this occurs in a year is small. The low RH within the space is most likely due to extremely low outdoor dew points that the roof top unit is not capable of overcoming. Without any form of humidification on the system, the space will act as a buffered version of what is happening outside. As the outside dew point drops, so will the inside dew point, bringing the RH in the space down. Since this only occurs during a handful of days each year, the best and simplest method for dealing with this issue is to employ a system of planned avoidance within the space. When the RH drops to dangerous levels for short periods of time the materials are safer inside storage boxes or hung close together under muslin covers. By not unboxing or exposing the materials at this time the risk posed by the low RH is lessened and the potential for damage is reduced. If materials must be worked on during periods of very low RH it would be safer to move them to another space within the facility with more stable conditions until the textile room returns to safe levels.

RECOMMENDATIONS

A summary of recommendations is listed here, with details below.

- Apply for an NEH SCHC Implementation grant to optimize RTU 6A & B, and RTU 2
- Add ceiling fans to the textile collection space
- Plan for short periods of low humidity rather than add additional humidification to the system
- Implement the original zoning and separation features intended for the space
- Connect the RTUs to a Building Management System to improve control
- Test managed system shutdowns to save on energy costs on RTU 2
- If zoning and separation changes are implemented, consider set point changes to improve preservation in collection spaces
- Reconsider use of the economizer on RTU 2
- Limit the amount of outside air brought into RTU 2
- Resolve the sub-cool heating issue
- Consider passive operation of the HVAC system
- Inspect RTU 6 A & B for super heating inside the units

Grants

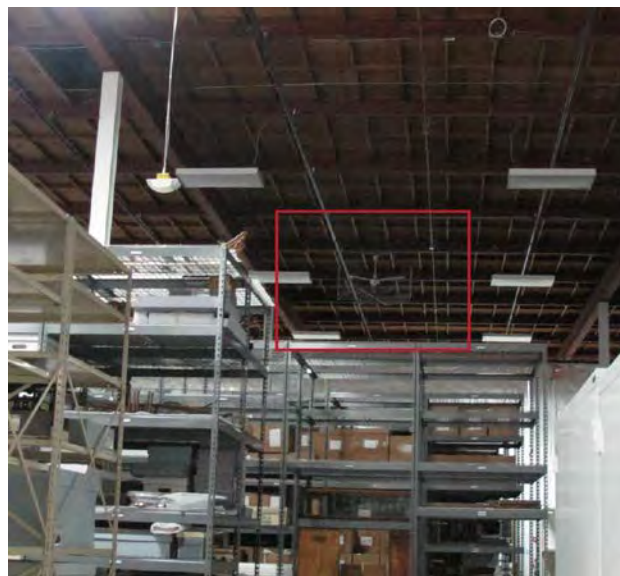
The library and textile storage areas represent nearly half of the total storage space at the MOHAI facility. The rest of the collection is stored in the three-dimensional storage area that is served by two air handling units, RTU 6A and 6B. MOHAI should consider applying for a NEH Sustaining Cultural Heritage Collections Implementation grant that would examine RTU 6A & B and RTU 2 with the goal of helping to improve the total environment for the collection rather than half of the collection space. These three units cover the entirety of the collection storage areas at the Resource Center facility.

Fans

The museum should investigate the possibility of adding ceiling fans to the textile collection space. This addition would help reduce the stacked air effect in the collection, produce a better mix of air, and improve the circulation of air from the diffusers. The museum is currently using similar fans in the three-dimensional storage space for the same purpose.

The library space could also benefit from ceiling fans, however the low ceiling and compact storage does not allow fans to fit in the space or to properly circulate air.

Humidification



Due to the type of system used, and the collection stored in the facility, the addition of system humidification or stand-alone humidification is not recommended. Adding humidification to the current unit, RTU 2, is not possible due to the system configuration. The only way to add humidification to the system as it is designed would be to add humidifiers inside the ductwork. The cost for this would be significant in relation to the few days of the year that humidification will actually be needed. The addition of in-duct humidifiers would require that water lines be added to supply water to the humidification system, increasing the risk for a leak that could potentially damage the collection.

Stand-alone humidification units require additional plumbing for both supply and drainage, again introducing the potential for a leak within the collection space. Another drawback to stand-alone humidification is that there is little control over the output of the unit. Stand-alone humidifiers have. Though many are programmable to set specific RH levels, stand-alone units have the potential to create areas of high relative humidity around the humidifier, while areas far from the unit may not.

Controlling the temperature set points in the space will greatly reduce the need for any humidification. During the dry days that occur avoid the handling of materials so the boxes or housing they are in can help buffer the materials from the dryness.

During the few days of the year where the RH in the space drops below 25% the best course of action in the textile space would be to employ a practice of planned avoidance with regard to the collection. This means that on days when the RH inside the facility is too low the staff should plan not to work on or move sensitive items. This will allow collections that are boxed or packed together closely, like the hanging costumes, to be buffered from the short-lived dryness in the environment. It is best during the few days of the year when this occurs that individual items are not exposed to space conditions for extended periods of time. While the grouped items work together as a unit to retain their moisture, individual materials can lose moisture quickly. If it is necessary to work on materials during this time, they should be moved to a space with a more stable humidity level.

Zoning and Separation

The staff at MOHAI has expressed an interest in implementing the zoning and separation features that were originally intended for the spaces. It is the opinion of the IPI staff that creating these features would benefit the collection. The library and textile spaces could remain on the same unit but would require installation of a downstream reheat for each space. The reheats would be connected to thermostats in each space that would control the temperature of the supply air only for these spaces. The main unit would create the supply air condition and the reheats would treat the air to bring it to the desired temperature. The separation feature originally intended for the space was a wall that separated the library collection space from the library staff area. Installation of this wall would allow the staff area to have its own reheat from RTU 2 or to be connected to a separate RTU. This would allow the staff area can be conditioned for human comfort while the collection spaces are kept cooler to help improve preservation.

Building Management System (BMS)

The facility should have all of the roof top units connected to a Building Management System (BMS) which will allow the facilities team to have more control over system settings

and adjustments. Under the current system design, any changes that need to be made must be performed by a technician trained in using a modular service tool to program each unit individually. In the event that multiple units need to be adjusted this can be costly and time consuming for the museum.

The BMS will allow easier programming of set point changes, seasonal changes, or managed shutdowns. A BMS system will allow staff to perform system diagnostics, and to be notified in the event of a malfunction. For example, if a heating or cooling coil were to fail the BMS system would send an alarm to the facilities staff before the malfunction became a major issue. Since the system can be viewed from a distance, a facilities person could check on an alarm after hours or respond and investigate an issue without being onsite.

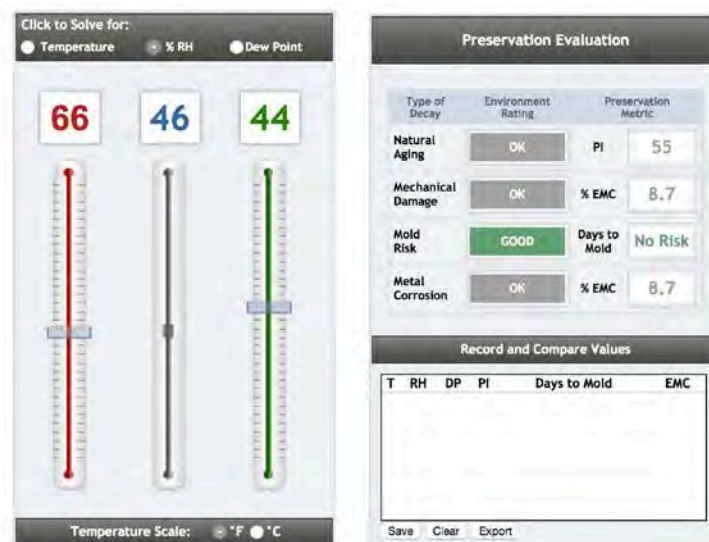
Shutdowns

The facility has shown some ability to hold temperatures when the HVAC system is not operating. Knowing this, a test should be performed on RTU 2 to evaluate how the facility would react to a scheduled shutdown of the mechanical system. These should range from 6 to 8 hours per day over a span of two weeks. During this time the system is completely shut down and the outside air remains closed. This will test the ability of the spaces served by RTU 2 to hold its temperature against the exterior heating or cooling loads. Short, preliminary daytime shutdown tests of 6 to 8 hours were initiated by MOHAI in March 2016. However, the lack of a BMS system made it impractical to undertake these tests for more than a week. In addition, continuing issues with RH made the MOHAI team hesitant to schedule any new tests, particularly during the problematic shoulder seasons.

We recommend that two tests be performed on the system, one in the summer (July/August) and one in the winter (December/January). The summer test should be performed in the evening and the winter test during the day. During the tests, data should be pulled from the loggers daily to ensure there are no issues in the space and that the conditions remain in a safe range for preservation. If at any point the conditions exceed the safe range the test should be halted and the data should be examined. Instituting 8-hour a day shutdowns would reduce energy consumption of the unit by roughly 33%. If successful, the process can be tested on and implemented in other spaces and units within the facility.

Set Points

The use of lower temperature set points within the space can produce a better long-term condition for the collections in both spaces. Over the last summer, the system had a history of producing a 66°F/46%RH/44° DP condition based on data collected from the PEM loggers. Though the system is capable of producing a cooler condition, human occupants in the library staff space would be effected.



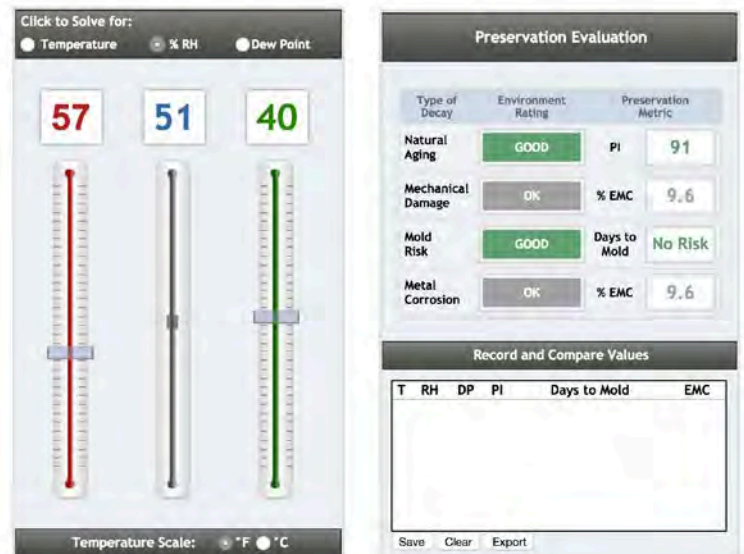
With no changes to the space as it is currently designed, the best conditions that can be produced for the collection spaces without having a negative impact on human comfort is 66°F/46% RH/44°DP. These conditions produce a Preservation Index (PI) of 55 which, like the overall metrics for the spaces, is adequate but could be better (See Appendix B for a description of IPI's Preservation Metrics®).

Separating the library collection space from the staff space would allow for cooler conditions in the collection area which would improve their preservation. As previously noted, this would require the construction of a wall separating the two spaces and either zoning RTU 2 or placing the staff area on a separate RTU. Without the proper reheat for the staff area or re-ducting another unit, there would be comfort complaints due to the cooler temperature and the potential for the warmer temperature to be restored.

With a new space layout the system set points could be lowered a few degrees in the storage spaces to provide a slightly better storage condition. A setting of 63°F/52%RH/44°DP would yield a better PI and the overall metrics would remain satisfactory. The lower temperature will require less reheat from the unit and should result in some cost saving over the season. With the staff area on its own unit or with its own reheat, human comfort is achieved while improving the preservation quality of the collection.



With the construction of a dividing wall in the library and cooler conditions available, it would be possible to attempt to achieve more from RTU 2. The previous recommendation used a dew point of 44° based on the dew point produced by the previous coil on the system. There is some data to indicate that the new coil installed on the system may be capable of achieving a 40° dew point. By lowering the temperature even more, a condition of



57°F/51%RH/40°DP could be achieved in the space. In this scenario the PI is improved by almost 40% compared to the current summer conditions. With staff space on a separate

zone there is no worry about being too cold. Again, this would use less reheat energy from the heater and provide energy savings over the season. Staff who may have to work in these spaces should plan to wear a coat or sweater if they need to access these areas.

Economizer

The economizer on RTU 2 should be disabled, or the control of the economizer should be altered. Use of the economizer is meant to bring in outside air as a means of free cooling—since less work needs to be performed on the air it saves on operation. While this method works well inside office buildings, the use of an economizer is not recommended for collection spaces. When trying to limit the moisture in the facility and to maintain a specific condition, the more outside air that is brought in results in the performance of more work to bring the air to a condition that is satisfactory for the collection. Limiting or eliminating the economizer should help reduce the amount of outside air that is used for this purpose.

If the intention is to keep the economizer functioning, MOHAI should investigate switching it to combination temperature/dew point control. Using this control will allow the economizer to operate only when outside air conditions are close to the interior conditions that the system is already trying to create. This way the system can still use the economizer for free conditioning while not having to perform as much work on the outside air that was brought in.

Limit Outside Air

With little occupancy inside the space, the outside air for RTU 2 can potentially be closed. There is little need for fresh air among the collections. Any fresh air that is introduced into the facility will most likely need to have work performed so that it will match the air already in the space. The less air brought in, the less work will need to be done by the system. If there are concerns over the amount of outside air needed, CO2 sensors should be installed to monitor the CO2 level inside the facility. When the CO2 reaches a high level the sensor will cause the outside air damper to open and bring in fresh air.

Resolve the Sub-cool Heating Issue

Resolving the system's sub-cool heating issue will greatly reduce energy consumption. Currently the system is spending about 30% of the year performing sub-cool heating operation, even when the supply air condition is warmer than the outside air. This operation is described and illustrated on page six of this report

A total of 62°F of sensible energy is used in this scenario (22°F of cooling, 36°F of heating, 4°F lost at the cooling coil). Resolving this issue should produce significant savings for the museum due to the amount of natural gas that is used during this operation. Controlling these swings in the system may save more money than using the economizer and would justify its deactivation.

The sub-cool and reheat cycling issue appears to be caused by the firing of all four stages of the heating coil. This is seen year round and not only during the winter months. The programmed reset temperatures could potentially be causing this issue. Here the space temperature sensor is seeing a low temperature condition and turning the heat on until the heating limit is reached. The engineers may be needed to determine how to remedy this

issue. Unfortunately, this issue may not be resolved by readjusting the heating and cooling limits and could instead require an upgrade in the heating equipment used on RTU 2.

Consider Passive Operation

Both the library and textile spaces could potentially benefit from passive operation of the HVAC system. Running the system passively would include operating the system less during the day, and only using the system if needed. This would eliminate running the system for the entire day to try to reach one specific temperature or RH level. Instead the facility would be allowed to drift between high and low limits and would only turn on if it reaches the limit. Once the space is satisfied the system would remain off until it is needed again.

Proper zoning would be needed to separate the library and textile rooms into individual spaces. The spaces would act independently from each other and RTU 2 would not work to treat both spaces when only one space needed it. Shutdowns should also be tested prior to using passive operations. The success of shutdowns would shed some light on the spaces ability to hold temperatures over a period of time. If data collected during the shutdowns show that the space cannot hold the temperature well it may not operate well using passive operation.

Three-Dimensional Storage

The three dimensional space should benefit from the same conditions that have been applied to RTU 2. Staff should test:

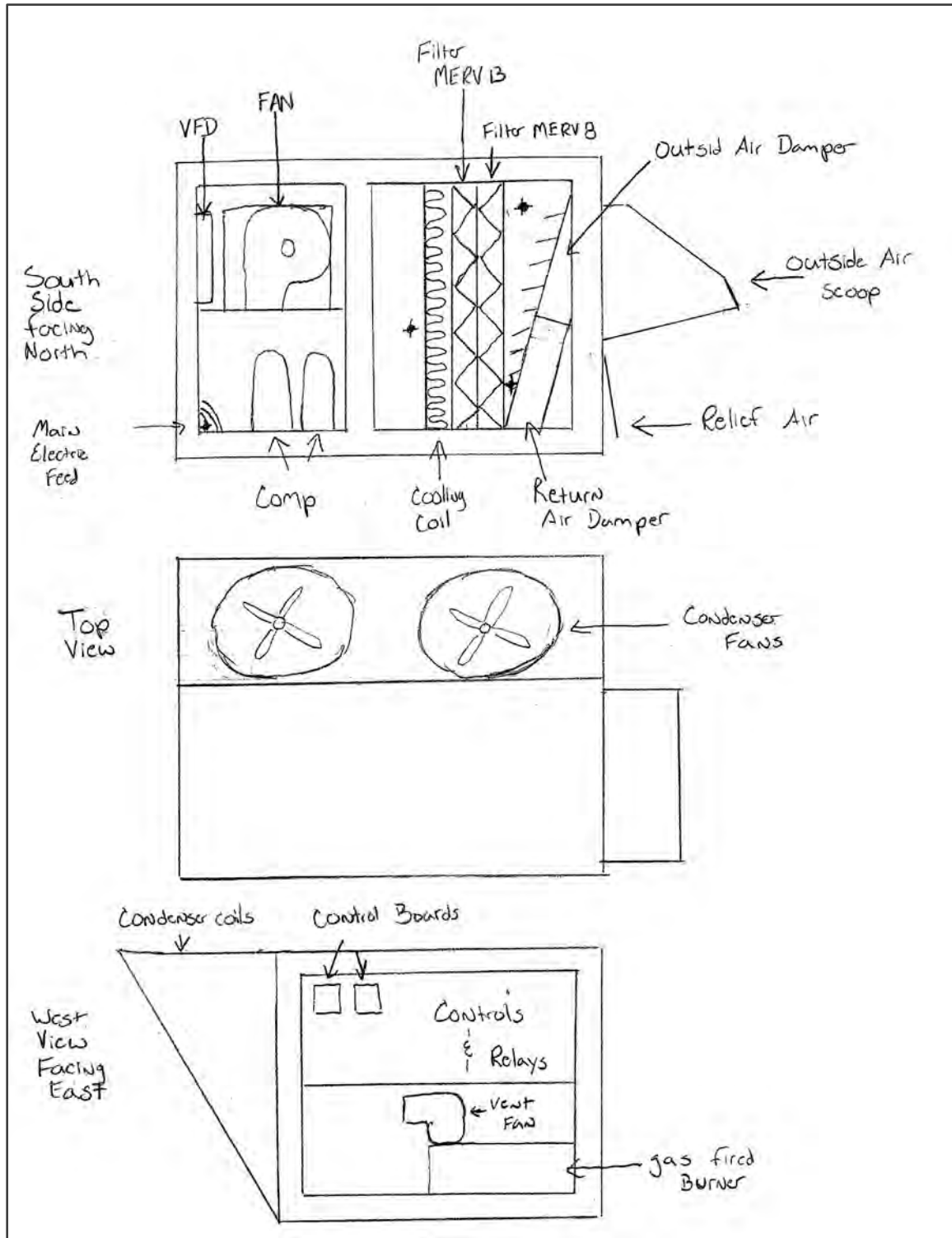
- the effectiveness of system shutdowns
- the use of cooler temperatures in the winter
- the passive operation of the system in the summer
- the use of sub-cooling and reheating
- the disablement of the economizer in this space

As with the RTU 2 spaces it is important to test these suggestions before they are implemented to ensure that they are appropriate for the collection, the air handling units, and the space.

Based on the findings from testing RTU 2, the units that serve the Three-Dimensional storage space (RTU 6A & B) should be inspected for super heating inside the unit. There is a possibility that the same program that is controlling the operation of RTU2 may be running on RTU 6A & B. These cycles are causing the unit to alternate from sub-cool reheat mode to sub-cool heating mode. This alternating is causing dramatic swings of 20-30°F in the supply air temperature. These back and forth cycles are happening about five times a day and they have a direct effect on the spaces, the collections, and energy consumption.

Checking the unit for cycling may involve the location of data loggers in the unit, placed in locations similar to those that were used inside of RTU 2. These locations include inside the return air at the unit, inside the outside air intake of the unit, after the cooling coil, and connected directly to a supply diffuser. The location of these loggers will help determine what each individual section of the unit is doing and indicate any excessive or unnecessary functions of the unit.

Appendix A: Diagram of Rooftop Unit (RTU) 2



Appendix B: IPI's Preservation Metrics®

Natural Aging

Measures:

The rate of "natural aging" as determined by the rate of spontaneous chemical change in organic materials.

- TWPI integrates the T and RH values as they change over time into a single estimate of the cumulative effects of the environment on the rate of chemical decay.
- TWPI is helpful as a quantitative comparison of the preservation quality of different storage locations or environments.

Applies to:

All Organic Materials (paper, textiles, plastics, dyes, leather, fur, etc).

TWPI Metric	Interpretation
TWPI > 75	GOOD
45 < TWPI ≤ 75	OK
TWPI ≤ 45	RISK

Metal Corrosion

Measures:

The effect of the environment on metal corrosion. The % EMC max represents the maximum amount of moisture that was present in hygroscopic collection materials. Because metallic corrosion is dependent on available moisture, the % EMC gives us an idea whether or not metallic objects (mainly ferrous metals) would corrode in such an environment.

Applies to:

Metals or materials with metal components.

Corrosion Metric	Interpretation
Max EMC ≤ 7.0	GOOD
7.1 ≤ Max EMC ≤ 10.5	OK
Max EMC > 10.5	RISK

Mold Risk

Measures:

The risk for growth of the xerophilic mold species on collection objects or in collection areas.

Applies to:

All organic materials (paper, textiles, plastics, dyes, leather, fur) or inorganic materials with organic films.

Mold Risk Metric	Interpretation
MRF ≤ 0.5	GOOD
MRF > 0.5	RISK

Note: There is no "OK" rating for mold risk. At a MRF of 0.5, conditions are appropriate for germination of spores. By alerting RISK of mold growth at germination, the user is aware of the potential of mold growth before any visible or vegetative mold will appear. This allows for time to react and prevent formation of vegetative mold.

Mechanical Damage

Measures:

Three aspects of moisture content that promote mechanical or physical damage:

1. Max % EMC: Is it too damp? Will paper curl? Will emulsions soften? Will wood warp?
2. Min % EMC: Is it too dry? Will paper become brittle? Will emulsions crack?
3. % DC: How great are the fluctuations between the most damp and the most dry? Has expansion and contraction - from absorption/desorption of water - put physical stress on the collection materials?

Applies to:

All organic materials (paper, textiles, plastics, dyes, leather, fur) or inorganic materials with organic films.

Mechanical Damage Metrics	Interpretation
Min EMC ≥ 5% AND Max EMC ≤ 12.5% AND %DC ≤ 0.5%	GOOD
Min EMC ≥ 5% AND Max EMC ≤ 12.5% AND 0.5% < %DC ≤ 1.5%	OK
Min EMC < 5% OR Max EMC > 12.5% OR %DC > 1.5%	RISK

Museum of History and Industry
Analysis of Mechanical Systems and Building Envelope of the MOHAI Resource Center
National Endowment for the Humanities Sustaining Cultural Heritage Collections Grant Program

Engineering Summary
Affiliated Engineers, Inc.
Rebecca Welch
Darren Boyle

Affiliated Engineers, Inc. was originally hired as peer reviewers for the initial construction project of the MOHAI Archival Storage facility in Georgetown. The preliminary project criteria required the 2D work area and archival storage spaces to be 60 +/- 5 deg F with 45% +/- 5% relative humidity (RH). Due to the proposed layout, in which a combined work space and a 2D archival storage area are in a shared space, the interior criteria was adjusted. The interior air temperature criteria was increased to accommodate the comfort of the occupants working in the combined space and the operating limitations of the packaged direct expansion rooftop air conditioning unit. The interior conditions of the 2D archival space were adjusted to 68 +/- 3 deg F and an RH level between 35 to 53%.

The rooftop unit (RTU), RTU-2, serves the 2D archival space, 2D work area, and also the textile archival storage area, trending of the installed system indicated that the equipment was not performing as required. RTU-2 was cycling and causing multiple swings in interior temperature and humidity throughout a 24 hour period. Adjustments to the unit's controls were implemented in March 2016 which helped to stabilize the unit and provide more consistent temperature and humidity control in the interior spaces. However, the adjustments still have not been able to maintain the required humidity range throughout the year.

From data loggers placed on-site in the interior zones, it was determined that the relative humidity in the 2D and textile archival spaces exceeds recommended humidity levels periodically throughout the year. The interior temperatures did show improved stabilization after the controls revisions as noted in the Interim Performance Report dated 10/01/15 – 03/31/16. In that report, the consistent interior temperatures achieved with the March 2016 RTU-2 controls revision was able to provide an improved Preservation Environment Evaluation with Risk metrics in the "OK" to "Good" range in lieu of the previously range of "OK" or "Risk". However, the supply air is not being sub-cooled enough to remove enough moisture from the mixed air (i.e. recirculated air with a low percentage of incoming outside air) which is still causing relative humidity levels greater than the established RH criteria. This is a limitation of the installed packaged rooftop unit, RTU-2.

In order to maintain RH levels within the prescribed criteria year round, it is recommended that standalone dehumidification units be provided for both the 2D the textile archival storage rooms. A dedicated unit is recommended for each storage area as interior conditions for each space vary based on the historical trends of the data loggers, different ceiling heights, and varying exterior wall exposures which affect leakage into the space. The dehumidification units would keep humidity levels below the 53% RH requirement all year round.

Continued on next page.....

In addition to the dehumidification units, we would recommend that a Building Management system (BMS) be installed. A BMS would connect all of the rooftop air conditioning unit controllers, proposed dehumidification units, room temperature sensors, relative humidity sensors (where applicable for archival spaces), equipment status monitoring, and outdoor air conditions to an easily accessible location. Please note that currently all equipment is located on the roof with only a fixed ladder with safety cage for access. The monitoring would allow the facilities personnel to react efficiently to equipment shut downs, adjust equipment set points to meet interior conditions, alarm when interior conditions exceed requirements, and trend internal humidity levels to verify that the interior conditions are adjusting as required by the facilities personnel in a steady seasonal drift.

Museum of History and Industry
Analysis of Mechanical Systems and Building Envelope of the MOHAI Resource Center
National Endowment for the Humanities Sustaining Cultural Heritage Collections Grant Program

Conservator Summary
Dana K. Senge

This project focused on examining physical spaces, testing equipment, gathering data, and understanding the mechanical systems that directly effect the library and textile storage areas at the Museum of History and Industry (MOHAI). The summary of climate tests and data, along with recommendations to improve the stability of the museum environment is expected to be submitted by participants from the Image Permanence Institute (IPI) in the Fall of 2016.

Assessment of the environment at the beginning of the project illustrated that existing equipment and settings create acceptable ranges of environmental conditions for much of the year, with only a few periods with too humid or too dry conditions. Staff has witnessed objects reacting to dry environments and one specific anecdote was shared: the Librarian witnessed photographs actively curling due to low humidity (approximately 20%).

As the museum and library staff continue their work to care for the collections, provide access to researchers, and prepare items for exhibit they will need to continue their awareness of the effect of the environment on objects. Recommendations from the IPI team are expected to range from adjustments to existing equipment to building improvements to new climate systems. Even with major investments in building improvements and climate systems to provide additional stability throughout the year, staff should be prepared for emergencies with harsh environmental conditions that may occur with system failures.

Establishing protocol to determine what extremes exist for these collection materials and guidelines for decision making and handling items when experiencing extremes of RH with help prepare staff in the event of a drastic climate shift. These steps may be incorporated with the museums emergency response plan in an effort to centralize these references. This protocol may be very brief. The curators and librarian may consider assessing activities that place objects at risk in low or high humidity situations, and how these activities may be modified to reduce damage during RH extremes. This may be as simple as minimizing handling/movement of objects or, at least, additional awareness while handling an object to minimize the risk of damage.

Table 1 lists the materials most commonly found in the library and textile collections, the acceptable RH ranges to minimize risk of damage to these material types, and the type of damage that could be caused to the materials when exposed to the RH extremes outside these ranges. In most situations, quick fluctuations of RH have minimal effect on materials. The most damaging situations are large, sharp changes followed by plateauing, dropping from 55% to 30% and staying at 30% for over a day for example, can cause desiccation in organic materials, commonly observed as fibers shrinking and becoming brittle. Short exposures are not considered damaging, even to thin composite objects such as photographs.

Table 1. (Compiled from Kite 2006, Lavedrine 2003, Shashoua 2008, and Timar-Balazsy 1998)

Material	acceptable RH range	Notes
Paper	30-50%	Humidity below 20% causes desiccation, brittleness, and breaking. Above 50% causes hydrolysis.
Photographic Emulsion	30-50%	Humidity below 20% can cause delimitation. Above 70% causes softening and adhesion.
Silver in Photograph	30-50%	Above 50% causes oxidation/reduction, mirroring, sulphiding
Magnetic tape (video and more)	30-50%	
Cellulose nitrate objects (film and fasteners/accessories)	< 40%	Exposure to higher humidity can cause chemical deterioration-nitric acid produced.
Cellulose acetate objects (film and fasteners/accessories)	< 40%	Exposure to higher humidity can cause chemical deterioration-acetic acid produced.
Wool	35-50%	Below 35% desiccation begins to occur and above 65% fibers swell and mold can grow.
Cotton	40-60%	Below 40% desiccation begins to occur and above 65% fibers swell and mold can grow.
Polyester	no recommended range in the literature	Can cause chemical reaction in alkaline environment (such as within buffered storage material) altering polymer structure.
Polypropylene	no recommended range in the literature	Resistant to moisture
PVC	30-50%	Can cause chemical reaction altering polymer structure.
Silk	40-55%	Below 40% desiccation begins to occur.
Leather	40-60%	Looses flexibility and more prone to breaks and rear below 40%, subject to mold and staining when exposed to 65% or higher.
Rubber	35-55%	Varies depending on manufacturing treatment.

Material	acceptable RH range	Notes
Metals	< 35%	Corrosion activity increases as humidity increases.

In general, recommended seasonal set ranges for the Pacific Northwest environment for the library materials and textiles collections are: 35-45% (40% +/- 5%) in the winter and 40-50% (45% +/- 5%) in the summer. Seasonal drift is recommended, allowing RH to drift during Spring and Fall, up or down over several weeks depending on the season, ideally adjusting 2 percentage points over two week periods.

References:

Kite, Marion and Roy Thomson. 2006. *Conservation of Leather and Related Materials*. Butterworth and Heinemann.

Lavedrine, Bertrand. 2003. *A Guide to the Preventive Conservation of Photograph Collections* J. Paul Getty Trust.

Shashoua, Yvonne. 2008. *Conservation of Plastics: Materials Science, Degradation and Preservation*. Butterworths and Heinemann.

Timar Balazsy, Agnes, and Eastop, Dinah. 1998. *Chemical Principles of Textile Conservation*. Butterworth and Heinemann.

Session Title: You Can't Always Get What You Want – Inconsistent RH

Date: 5/8/2017 1:30 – 2:45 PM

Track: Facilities Management

Format: Talk Show

Presenters:

Betsy Bruemmer (Moderator) MOHAI

Clara Berg Textiles Specialist, MOHAI

Jeremy Linden Preservation Specialist, IPI

Dana Senge, Conservator

Jason Young, Snr. Manager Facilities and Security, MOHAI

Session Description

A renovated building and a new HVAC system should give you the preservation environment you seek, shouldn't it?! But relative humidity levels were too high in the spring and fall, and too dry in the winter for our archival and textile collections. Initial consultations with experts resulted in a variety of theories but no definitive solution. With the support of NEH, The Museum of History and Industry (MOHAI) worked with the Image Permanence Institute to revisit the mystery and develop a strategy to achieve an appropriate and sustainable preservation environment for the collection. This session will explore the problem and solution through the varying perspectives of mechanical equipment, facilities, conservation, and collections experts.

Information For Reviewers

This session presents the diverse views of IPI consultants, collections, facilities, and conservation professionals in considering the same problem. This approach enabled us to escape crisis mode, expand our thinking and develop the most effective solution for our situation. Participants will discuss initial impressions, misguided assumptions and revelations over the two year planning grant period. While the Museum is located in the Pacific Northwest, the challenging relationship between climate, building environment and HVAC systems is a common one. As museums of all sizes strive for sustainable solutions, we offer our experience in hopes that it will encourage and inspire others to broaden their understanding of the museum environment.

Learner Outcomes

What new skills, strategies or knowledge will participants gain as a result of attending your session?

Learner Outcome 1

Build knowledge of variables at play between the environment, the building envelope and hvac systems.

Learner Outcome 2

Broaden understanding about the acceptable ranges of relative humidity as they pertain to material type and museum practices.

Learner Outcome 3

Increase knowledge about sustainable solutions for artifact preservation through discussion of the project's analysis and conclusion.